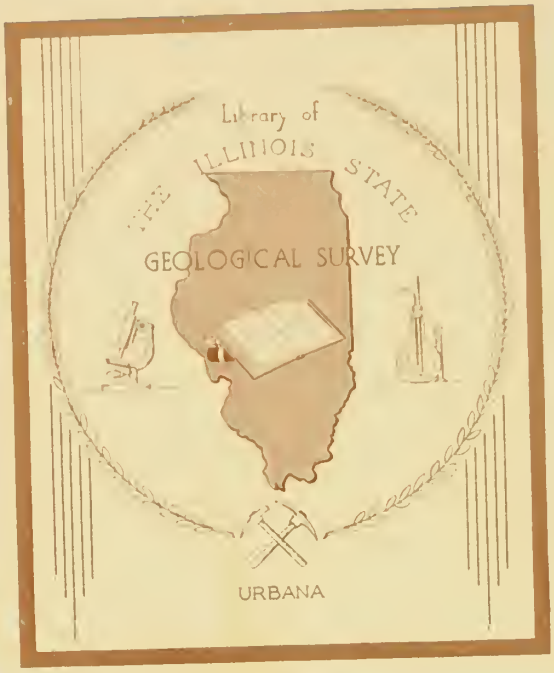

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PRELIMINARY GEOLOGIC INVESTIGATIONS OF ROCK TUNNEL SITES FOR FLOOD AND POLLUTION CONTROL IN THE GREATER CHICAGO AREA

T. C. Buschbach
George E. Heim

Prepared in cooperation with the Metropolitan Sanitary District of Greater Chicago and its consultants

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PRELIMINARY GEOLOGIC INVESTIGATIONS OF ROCK TUNNEL SITES FOR FLOOD AND POLLUTION CONTROL IN THE GREATER CHICAGO AREA*

T. C. Buschbach and George E. Heim†

ABSTRACT

A system of over 100 miles of tunnels in the bedrock has been proposed for the greater Chicago area to intercept overflow from the existing combined sanitary-storm water sewer system and to convey it to temporary storage chambers excavated in the rock.

Geologic investigations made during a study for the tunnel sites included test drilling and coring, geophysical logging of boreholes, laboratory testing of samples, seismic surveying, and testing for ground water. The drilling, coring, and logging furnished data that will be of considerable help in mapping and describing the individual units of Silurian and Ordovician strata of the area. The seismic survey indicated numerous closed depressions on the surface of the bedrock and also suggested that several faults with displacements of 10 to 50 feet are present on the top of the Galena Group.

INTRODUCTION

About 800 square miles of northeastern Illinois can be conveniently included in the greater Chicago area. As defined in this report, the area includes the city of Chicago, most of Cook County, eastern Du Page County, and a portion of northern Will County (fig. 1). The topography of the area is

* Prepared in cooperation with the Metropolitan Sanitary District of Greater Chicago, Harza Engineering Company, Bauer Engineering, Incorporated, Seismograph Service Corporation and its Birdwell Division, Layne-Western Company, and Dikor-Groves.

† Dr. Heim is a geologist for Dames and Moore, Consulting Engineers in the Applied Earth Sciences, Chicago. He was formerly associated with Harza Engineering Company, Chicago.

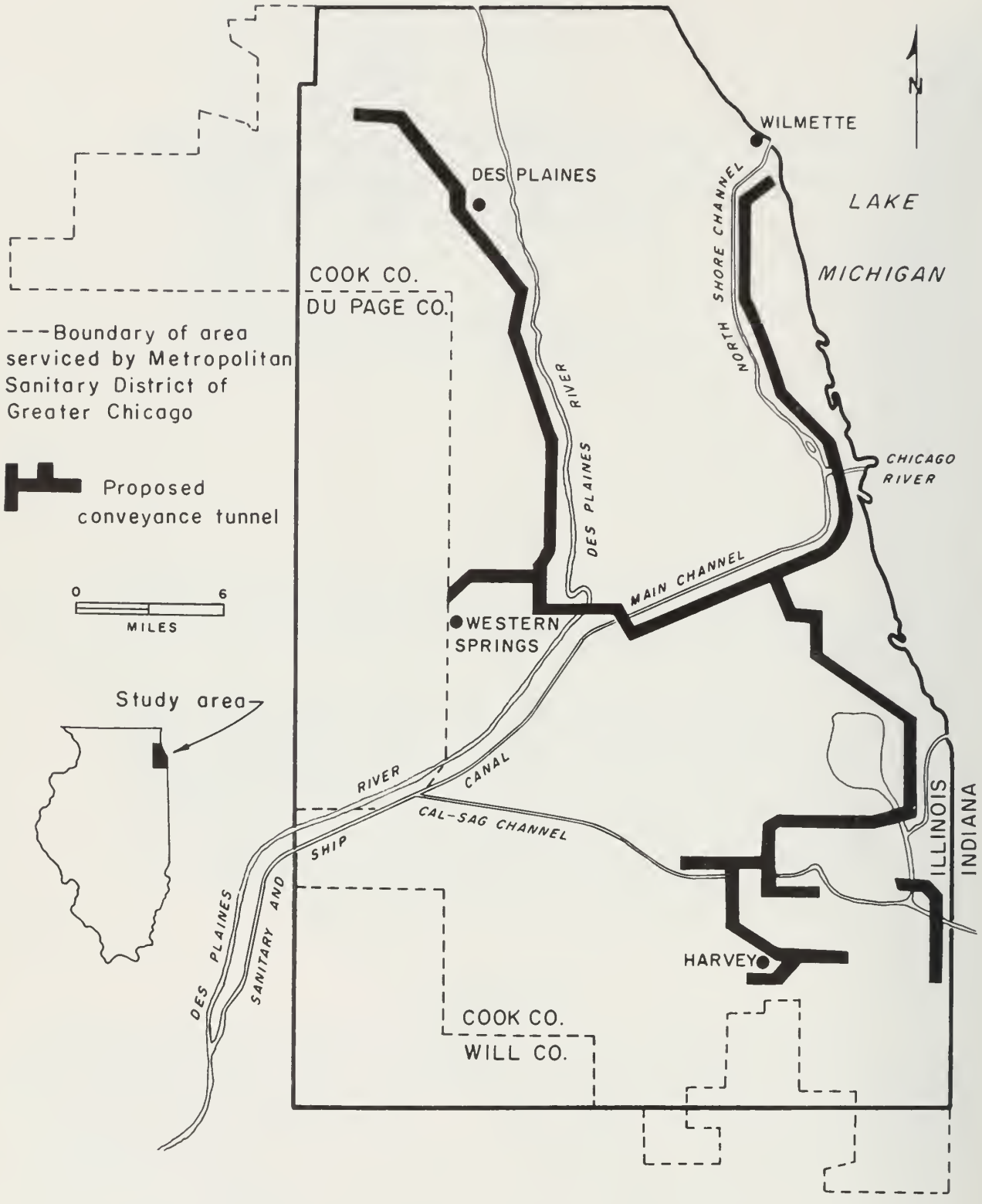

Fig. 1 - Proposed locations of conveyance tunnels in the greater Chicago area (after Neil, 1971, fig. 5).

relatively flat, the maximum relief being not much over 200 feet. Consequently, most small streams have low gradients and are subject to flooding.

The greater Chicago area includes more than 5½ million people and a multitude of varied industries. Removal of storm water runoff and domestic and industrial wastes from an area such as this poses a tremendous challenge. The city of Chicago and the suburban cities, towns, and villages generally install and maintain their local sewers. Throughout much of the area the Metropolitan Sanitary District of Greater Chicago maintains a system of interceptors to collect the sewage and storm water runoff and to direct the waters through one of its three treatment plants.

The central 360 square miles of the Chicago area has a combined sewer system that was built to receive both storm water and raw sewage. Urbanization has increased the runoff of storm water to the point that the limited capacities of sewers and stream outlets in the existing system are inadequate at times of heavy rainfall. In some areas the excess water collects in basements, underpasses, and streets. The water is polluted and becomes a hazard to health as well as to property. When the sewer and treatment system is inadequate to handle the storm water, some relief is obtained at overflow points by the discharge of a mixture of storm water and raw sewage into Illinois streams. On very rare occasions, when overflows are too large for the waterway system, the mixture must be discharged into Lake Michigan.

To find a means of alleviating these conditions, the Metropolitan Sanitary District of Greater Chicago, the city of Chicago, and the Illinois State Division of Waterways studied several possible solutions, including (1) separate storm and sewage systems, (2) temporary storage of polluted storm waters in widely distributed surface sites until they can be processed through a treatment plant, and (3) a system of large-diameter deep tunnels and underground chambers for the conveyance and temporary storage of polluted storm waters.

Complete separation of the combined sewer systems would reduce the pollution due to spillage of excess storm waters into the waterways. However, the Harza Engineering Company and Bauer Engineering, Incorporated, who were engaged to evaluate the possible solutions, advised that the cost of building separate sewer systems in the Chicago area would be economically impractical. Also, the disruption of traffic on nearly every street in the city and the inconvenience of reworking plumbing in so many houses and buildings are almost inconceivable.

According to reports by Harza Engineering Company and Bauer Engineering, Incorporated (1968a, 1968b), temporary storage sites at the surface in and near Chicago would be expensive and difficult to obtain because urbanization is so extensive. They reported that even if the surface storage sites were available, the combined sewer overflows probably could not be delivered to the reservoirs at high enough rates to prevent local flooding.

The Harza and Bauer reports rejected the first two solutions to the problems of flooding and pollution and favored the system of deep tunnels.

Acknowledgments

The Metropolitan Sanitary District of Greater Chicago made available to the Illinois State Geological Survey the reports prepared by its various consultants. Information from these reports was used as a partial basis for this paper.

The consulting engineers for the Deep Tunnel Project were Harza Engineering Company and Bauer Engineering, Incorporated, both of Chicago. The seismic survey was made by Seismograph Service Corporation, Tulsa, Oklahoma. Geophysical logging of boreholes was by the Birdwell Division of Seismograph Service Corporation. Drilling and testing for ground water was done by Layne-Western Company, Aurora, Illinois, and Dikor-Groves, Carmi, Illinois, did the core drilling.

The Illinois State Geological Survey has assisted the Metropolitan Sanitary District of Greater Chicago and its consultants by furnishing data on the general geology of the area, by examining cores, and by helping to develop stratigraphic information needed for this project.

DEEP TUNNEL PROJECT

The system of deep tunnels and underground chambers proposed in the Harza and Bauer reports (1968a, 1968b) to the Metropolitan Sanitary District of Greater Chicago provides for the temporary underground storage of mixed storm water and sewage overflow. Upon completion, the project is expected to (a) protect the Illinois Waterway System and Lake Michigan from pollution by the mixed overflow, (b) reduce the channel flood flows, (c) increase hydraulic gradients on the local sewers, (d) reduce the flooding of basements, streets, and underpasses, (e) improve the degree of sewage treatment by maintaining an even flow through the treatment plants, (f) increase the recreational use of the waterways by decreasing pollution, and (g) possibly provide electric power during periods of peak demand.

The Deep Tunnel Project consists of four essential parts (fig. 2). First, a series of vertical shafts located at the overflow points of the existing sewer system will intercept the combined sanitary and storm water overflow. Second, a network of rock tunnels located in dolomite formations about 150 to 300 feet below the surface and others about 700 to 800 feet below the surface will convey the overflow water from the vertical shafts. Third, large mined chambers more than 800 feet deep will provide temporary storage for overflow; and, fourth, reservoirs at the surface will receive the water pumped from the underground chambers and store it until it can be passed through a waste treatment plant and discharged into the waterways.

The Deep Tunnel Project could be expanded to include a hydroelectric generating facility. The overflow can be pumped from the underground reservoir and stored in a surface reservoir until power is needed. The water can then be released to the underground reservoir through an underground powerhouse to provide electric power in periods of peak demand.

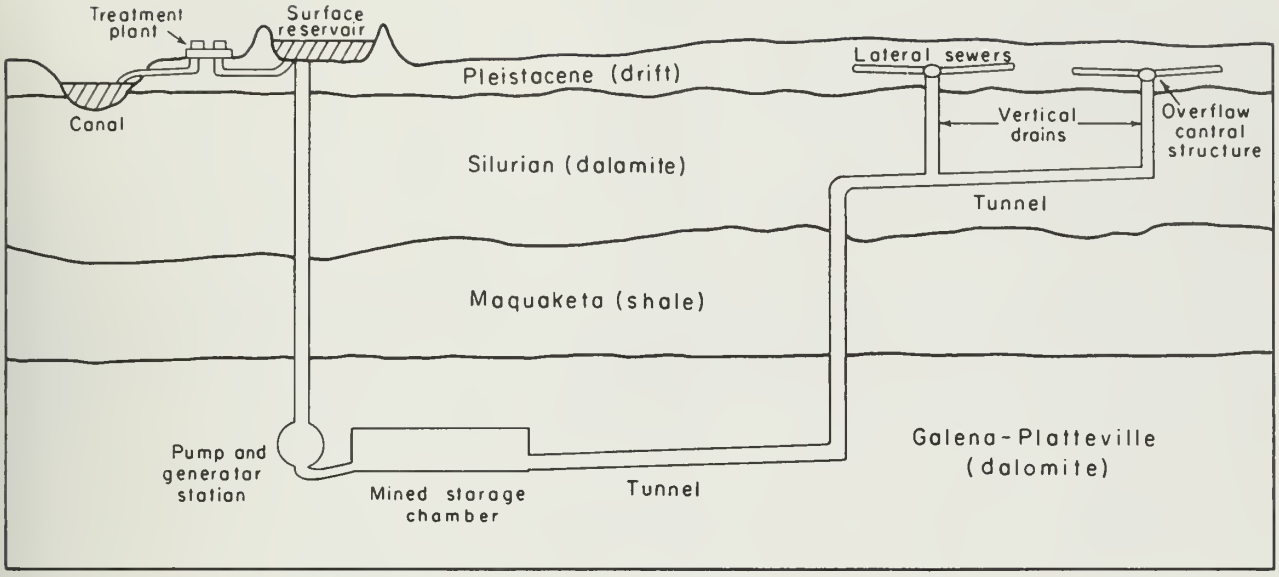

Fig. 2 - Diagrammatic sketch of a proposed plan for the Deep Tunnel Project. Depth to the storage cavern is about 800 feet. Interpretation by T. C. Buschbach (in Willman, 1971, fig. 27).

Ultimately the proposed system would consist of 100 to 150 miles of tunnels with diameters ranging from 6 to more than 30 feet. It would intercept the major overflow throughout the Chicagoland area. The rock tunnels would increase hydraulic gradients of the existing sewers and thereby reduce flooding. The mined storage chamber or chambers would provide temporary storage for the water from the severe storm that might occur once in 100 years. All the temporarily stored water would be treated prior to release, thereby reducing pollution of the waterways.

The layout of the various project elements has not yet been finally determined, although the first tunnels are under construction. Neil (1971) discussed some of the concepts of the Deep Tunnel Project that are under consideration. Temporary storage of flood water in abandoned quarries also is being considered.

The geologic requirements for the Deep Tunnel Project include (1) rock strata thick enough for the tunnels and the mined storage area, (2) rock capable of providing long-term stability with a minimum of support and lining, (3) rock with fairly uniform characteristics suitable for excavation by mole tunneling machines, and (4) a minimum of ground-water flow.

To protect aquifers from contamination by the outward seepage of storm water from mined storage reservoirs, a system was proposed that would maintain a positive ground-water pressure higher than the pressure of the storm water in the unlined structures. Any seepage that occurred would therefore be inward to the storm water rather than outward to the ground water.

To determine the technical feasibility of the Deep Tunnel Project, geologic investigations were made in 1967 and 1968. Quarries and natural outcrops in northeastern Illinois and mines in northwestern Illinois were studied

Time Stratig.			Rock Stratigraphy			GRAPHIC COLUMN	Thickness (ft)	KINDS OF ROCK
SYSTEM	SERIES	STAGE	MEGA-GROUP	GROUP	FORMATION			
QUAT.	PLEIS.						0-200	Till, sand, gravel, silt, clay, peat, marl, loess
SILURIAN	NIAGARAN		Hunton		Racine		0-300	Dolomite, pure in reefs, mostly silty, argilloceous, cherty between reefs
					Waukesha		0-20	Dolomite, even bedded, slightly silty
					Joliet		40-70	Dolomite, shaly and red at base; white, silty, cherty above; pure at top
	ALEX.				Konkakee		20-50	Dolomite; thin beds; green shale partings
					Edgewood		0-100	Dolomite, cherty, shaly at base where thick
ORDOVICIAN	CIN.	RICH.		Maquoketa	Neda		0-15	Oolite and shale, red
					Brainard		0-100	Shale, dolomitic, greenish gray
					Ft. Atkinson		5-50	Dolomite; green shale; coarse limestone
		MAY. ED.			Scales		90-120	Shale, dolomitic, gray, brown, black
	CHAMPLAINIAN	TRENT.	Ottawa	Galena	Wise Lake		170-210	Dolomite, buff, pure
					Dunleith			Dolomite, pure to slightly shaly; locally limestone
					Guttenberg		0-15	Dolomite; red specks and shale partings
		BLACKRIVERAN		Platteville	Nachusa *		0-50	Dolomite and limestone, pure, massive
					Grand Detaur		20-40	Dolomite and limestone; medium beds
					Mifflin		20-50	Dolomite and limestone, shaly, thin beds
					Pecatonica		20-50	Dolomite, pure, thick beds
				Ancell	Glenwood		0-50	Sandstone and dolomite, silty; green shale
					St. Peter		100-400	Sandstone, medium and fine grained; well rounded grains; chert rubble at base
	CANADIAN		Knox	Prairie du Chien	Shakopee		0-20	Dolomite, sandy; oolitic chert; algal mounds
					New Richmond		0-10	Sandstone, fine to coarse
					Oneota		150-200	Dolomite, pure, coarse grained; oolitic chert
					Gunter		0-15	Sandstone, dolomitic
CAMBRIAN	CROIXAN	TREMP.			Eminence		50-100	Dolomite, sandy
					Potosi		90-150	Dolomite; drusy quartz in vugs
		FRAN.			Franconia		50-140	Sandstone, glauconitic; dolomite; shale
					Ironton		100-150	Sandstone, partly dolomitic, medium grained
		DRESBACHIAN			Galesville		10-100	Sandstone, fine grained
					Eau Claire		370-450	Siltstone, dolomite, sandstone and shale, glauconitic
			Potsdam		Mt. Simon		1700-2400	Sandstone, fine to coarse; quartz pebbles in some beds
PRECAMBRIAN SYSTEM								Granite

* Includes a few inches to a few feet of the Quimbys Mill Formation

Fig. 3 - Sequence of rock strata in the greater Chicago area (modified from Willman, 1971, fig. 5). Abbreviations: Alex. - Alexandrian; Cin. - Cincinnatian; Ed. - Edenian; Fran. - Franconian; May. - Maysvillian; Pleis. - Pleistocene; Quat. - Quaternary; Rich. - Richmondian; Tremp. - Trempealeauan; Trent. - Trentonian.

to evaluate weathering characteristics, jointing, and mining characteristics of the various stratigraphic units that are present in the Chicago area. Data from wells in the Chicago area were used to prepare maps showing the structure and thickness of selected rock units. The subsurface exploration program included seismic surveying, test drilling, geophysical borehole logging, laboratory testing of core samples, and drilling and testing for ground water. The subsurface data from this project will contribute greatly to the understanding of the detailed geology and ground-water hydrology in the Chicago area.

Additional subsurface exploration is continuing, and studies of the data collected for this project will no doubt continue for many years. This report is a preliminary analysis of data from the feasibility study, and the maps presented here are subject to reinterpretation as more data become available.

GEOLOGIC SETTING

The Greater Chicago Area is located on the Kankakee Arch, a broad, gently sloping arch of Paleozoic sediments that connects the Wisconsin Arch lying to the northwest with the Cincinnati Arch to the southeast. It also separates the Illinois Basin from the Michigan Basin (Buschbach, 1964, fig. 1). The area we studied is northeast of the crest of the Kankakee Arch, and thus the regional dip of the bedrock units is eastward into the Michigan Basin.

Most of the area is mantled by surficial material as much as 200 feet thick that was deposited by Pleistocene glaciers that repeatedly covered the area and by the various high-level stages of Lake Michigan. Beneath the mantle of glacial drift and lacustrine deposits, the bedrock consists of Silurian dolomite, which is about 50 to 500 feet thick. The surface of the bedrock is a dissected, undulating plain in which a well developed pattern of stream valleys is entrenched. At some places the valleys are more than 100 feet deep and appear to have steeply sloping sides. Glacial deposits filled the valleys, and the present drainage patterns have little relation to the earlier valleys.

Underlying the Silurian rocks in northeastern Illinois are from 700 to 1100 feet of Ordovician strata and from 2000 to 3500 feet of Cambrian strata. Below the Cambrian are Precambrian basement rocks, composed chiefly of granite.

STRATIGRAPHY

The sequence of Pleistocene, Silurian, Ordovician, and Cambrian rock formations is shown in figure 3. Pleistocene deposits are unconsolidated formations of gravel, sand, silt, and clay laid down on bedrock, chiefly by melting glaciers. To a lesser extent some of these sediments were also deposited in rivers, streams, and lakes. Pleistocene stratigraphy of the Chicago area was described by Bretz (1955) and Willman (1971). Only the bedrock stratigraphy is discussed in this report.

Rocks of Silurian, Ordovician, and Cambrian ages are marine and were deposited in shallow to moderately deep seas. The Silurian rocks were described

by Bretz (1939) and Willman (1943, 1962, 1971). Ordovician and Cambrian rocks of northeastern Illinois were described in detail by Buschbach (1964).

Silurian System

The Silurian System is represented in northeastern Illinois by dolomite that ranges from very pure to very silty and is argillaceous and cherty (fig. 3). The upper part of the Silurian is characterized by randomly distributed reefs of pure dolomite surrounded by well layered, silty, interreef dolomite. The lower part of the Silurian consists of regularly bedded dolomite units that range from pure to argillaceous or cherty. They are distinctive units that can be traced widely in this area (Willman, 1971). The Silurian System generally thickens to the southeast. It is locally less than 50 feet thick in the northwestern part of the area, but it reaches a thickness of nearly 500 feet in the southeastern part (Suter et al., 1959, fig. 27). Significant unconformities occur at the top and base of the Silurian. In this area the Silurian strata are differentiated into two series: the Alexandrian below and the Niagaran above. Much of the proposed tunneling is to be done in Niagaran rocks.

Niagaran Series

Racine Dolomite - The Racine Dolomite is a variable unit consisting of pure, gray, massive, vuggy dolomite in large reefs, and of argillaceous, silty, fine-grained, thin-bedded, grayish brown dolomite in interreef areas. The Racine is about 300 feet thick along the eastern edge of the Chicago area. It thins westward by truncation and is absent in the northwestern part of the area.

Waukesha Dolomite - The Waukesha Dolomite is a fine-grained, silty, well bedded, gray dolomite. It is present in the southwestern part of the area, where it is as much as 20 feet thick. The Waukesha appears to be absent in the eastern and northern parts of the area.

Joliet Dolomite - The Joliet Dolomite is 40 to 70 feet thick in the area. It consists of three distinctive members.* An upper unit, the Romeo, is a light gray to white, pure, porous dolomite. It is 10 to 25 feet thick. A middle unit, the Markgraf, consists of silty and slightly argillaceous dolomite that is light gray and very fine grained. It is 20 to 30 feet thick. A basal unit, the Brandon Bridge, is argillaceous, red or greenish gray dolomite interbedded with red and green shales. It is present in the northern and western parts of the area, where it varies from a few to 20 feet thick.

Alexandrian Series

Kankakee Dolomite - The Kankakee Dolomite consists of light gray to pinkish gray, fine-grained dolomite in beds 1 to 3 inches thick, which are

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* The names Romeo, Markgraf, and Brandon Bridge are being introduced by Willman (in preparation) to replace the letters C, B, and A previously used (Willman, 1962). The names have been used recently in Deep Tunnel Project reports prepared by Harza Engineering Company, Birdwell Division, and Seismograph Service Corporation for the Metropolitan Sanitary District of Greater Chicago.

separated by thin green shale partings. Chert nodules are present but not abundant. Scattered sand grains and a little glauconite are common at the base. At the top of the formation there is a massive bed of white dolomite that is about 2 feet thick. The Kankakee ranges from 20 to 50 feet thick in the area, but it is commonly about 40 feet thick.

Edgewood Dolomite - The Edgewood Dolomite is a variable unit that grades upward from a brown to gray, shaly dolomite at the base to a light brown dolomite with numerous beds and nodules of chert at the top. The formation has a maximum thickness of about 100 feet where it fills broad channels that were cut into the underlying rocks of the Maquoketa Group. It thins over divides between channels and is locally absent where a full section of Maquoketa is present.

Ordovician System

The Ordovician System in Illinois is divided, from the top, into the Cincinnatian, Champlainian, and Canadian Series. Pronounced unconformities occur at the tops of the Cincinnatian and Canadian strata, and a lesser unconformity occurs at the top of the Champlainian.

Cincinnatian Series

The Cincinnatian Series, the uppermost series of the Ordovician System, is represented in the Chicago area by shaly strata assigned to the Maquoketa Group. A minor unconformity occurs at the base of the series, and a significant unconformity occurs at the top. As much as 100 feet of shale was removed from some localities before the overlying Silurian rocks were deposited.

Maquoketa Group

Neda Formation - The Neda Formation consists of a few feet of red shale that locally contains hematitic oolites. In this area the Neda is present only where the underlying Brainard has not been eroded and the total Maquoketa thickness exceeds 190 feet.

Brainard Shale - The Brainard Shale is a greenish gray, silty, dolomitic shale with interbedded layers of silty dolomite. It has a maximum thickness of about 100 feet, but in places it has been entirely removed by pre-Silurian erosion.

Fort Atkinson Formation - The Fort Atkinson consists chiefly of fine- to coarse-grained, fossiliferous dolomite or limestone and some interbedded green or brown shale. It ranges from 5 to 50 feet thick.

Scales Shale - The Scales Shale, at the base of the Maquoketa Group, is grayish brown shale that is silty and dolomitic. It contains interbeds of silty dolomite, most of which are an inch or two thick. The Scales is present and easily recognized throughout the area. It varies from 90 to 120 feet thick.

Champlainian Series

The Champlainian Series in this area is represented by three groups of rocks (Templeton and Willman, 1963). At the top, the Galena Group consists chiefly of medium to thick-bedded dolomite with a little limestone. The underlying Platteville Group consists of dolomite and limestone formations that are somewhat thinner bedded than the Galena strata. Mined storage reservoirs and some large-diameter tunnels will probably be excavated in the Galena and Platteville rocks if the project plan is carried out.

At the base of the Champlainian is the Ancell Group, which consists chiefly of sandstone that unconformably overlies older Ordovician and Cambrian formations.

Galena Group

Wise Lake and Dunleith Formations - The Wise Lake and Dunleith Formations consist of thick-bedded, pure, fine- to medium-grained, light brown dolomite that grades to fine-grained limestone in some places. Oil-stained vugs are common in the upper few feet of this dolomite sequence, and a concentration of pyrite occurs at the very top. The Wise Lake and Dunleith are quite similar and cannot be separated consistently in this area. They have a combined thickness of from 170 to 210 feet.

Guttenberg Formation - The Guttenberg Formation consists of brown dolomite or limestone that characteristically contains red specks and thin reddish brown shale partings. It can be recognized everywhere in the area when good drilling samples or cores are available, and it serves as a good marker bed. The Guttenberg ranges from about 4 inches to 15 feet thick.

Platteville Group

Quimbys Mill Formation - The Quimbys Mill is a thin unit at the top of the Platteville that has been recognized recently in cores for the tunnel project. It consists of a few inches to a few feet of dolomite or limestone that is light brownish gray and very fine grained. Thin beds of dark gray or dark brown shale are present in some places.

Nachusa Formation - The Nachusa Formation consists of fine- to medium-grained, light brown dolomite or fine-grained limestone. It reaches a maximum thickness of 50 feet in this area, but it is locally absent.

Grand Detour Formation - The Grand Detour Formation is a light brownish gray, fine-grained dolomite or limestone that has dark gray mottling. Thin zones of dark gray or reddish brown shale partings are common near the top of the formation. The Grand Detour is 20 to 40 feet thick.

Mifflin Formation - The Mifflin Formation is light gray, very fine-grained, thin-bedded dolomite or limestone with green or gray shale partings. It is 20 to 50 feet thick.

Pecatonica Dolomite - The Pecatonica Dolomite is a relatively pure, vuggy, light brown to grayish brown, fine-grained dolomite with floating sand

grains in the lower few feet. It grades to light brown, very fine-grained limestone in some localities, but it is commonly the most dolomitic of all the Platteville Formations. The Pecatonica is 20 to 50 feet thick.

Ancell Group

Glenwood Formation - The Glenwood Formation consists of sandstone with some shale and dolomite. The sandstone is slightly coarser grained and not as well sorted as the underlying St. Peter. The Glenwood is not recognized in the southern part of the area. To the north and west it is as much as 50 feet thick.

St. Peter Sandstone - The St. Peter Sandstone is a clean, fine- to medium-grained, well sorted sandstone. It is generally porous and permeable. At its base the formation includes a unit of shale and chert rubble (Kress Member) that varies from a few inches to over 100 feet thick. The thickness of the St. Peter is commonly a little less than 100 feet to a little over 200 feet in the area, but locally it is more than 400 feet thick where it fills older valleys and sinkholes that have been cut into the underlying surface.

Canadian Series

The strata of the Canadian Series are chiefly dolomite and a few thin beds of sandstone. The four formations in the series compose the Prairie du Chien Group. In some places these strata were entirely removed by solution and erosion before deposition of the overlying St. Peter Sandstone (Buschbach, 1961).

Prairie du Chien Group

Shakopee Dolomite - The Shakopee Dolomite consists of fine-grained dolomite with oolitic chert nodules and thin beds of sandstone and shale. The Shakopee immediately underlies the prominent sub-St. Peter unconformity and consequently has been entirely removed from most of the area. Where present it is a few to 20 feet thick.

New Richmond Sandstone - The New Richmond Sandstone is a medium-grained sandstone interbedded with a little sandy dolomite. It is recognized only in the southwestern part of the area, where it is a few feet thick.

Oneota Dolomite - The Oneota Dolomite consists of relatively coarse-grained dolomite with some interbedded fine-grained units. The upper half of the formation is relatively pure, with only a few scattered chert nodules. Some of the chert is oolitic. The lower half of the formation contains numerous beds and nodules of chert and some thin beds of green shale. The Oneota is 150 to 200 feet thick.

Gunter Sandstone - The Gunter Sandstone consists of discontinuous beds or lenses of fine- to medium-grained sandstone interbedded with dolomite and green shale. The Gunter is absent throughout much of the Chicago area, and where it is present it is not known to be over 15 feet thick.

Cambrian System

Croixan Series

The Cambrian strata of this area are assigned to the Croixan Series of late Cambrian age, although it is possible that the thick Mt. Simon Sandstone may include older deposits.

Eminence Dolomite - The Eminence Dolomite, the uppermost Cambrian formation, is composed of light colored sandy dolomite, with a few thin beds of sandstone at or near its base. The dolomite is fine- to medium-grained and contains oolitic chert nodules. In much of the area the Eminence has been removed by pre-St. Peter solution and erosion. Its reconstructed thickness increases southward from a little less than 50 to about 100 feet.

Potosi Dolomite - The Potosi Dolomite is a light gray to brown, fine-grained dolomite. The formation is relatively pure and was apparently subjected to a considerable amount of solution by ground water. It is commonly vuggy and locally it is cavernous. The vugs are lined with drusy quartz crystals. The caverns appear to be vugs that are enlarged and joined by solution effects. They are most common from 5 to 50 feet below the top of the Potosi, but they have been reported throughout the formation. These caverns and fissures cause difficulties in drilling wells through the Potosi; quite commonly the drill bit drops 3 to 5 feet without encountering solid rock. The Potosi is 90 to 150 feet thick throughout much of the area, but it has been locally thinned or removed by pre-St. Peter solution and erosion.

Franconia Formation - The Franconia Formation, below the Potosi, consists of fine-grained, pink to gray, dolomitic, argillaceous sandstone that is commonly very glauconitic. It contains thin beds of red or green shale. The Franconia is 50 to 140 feet thick.

Ironton Sandstone - The Ironton Sandstone is a clean, medium-grained, moderately sorted, dolomitic sandstone. The dolomite is present as cementing material, and up to 25 percent of the formation consists of beds, a few inches to a few feet thick, of very sandy dolomite or sandstone that is well cemented by dolomite. The Ironton is 100 to 150 feet thick in the area.

Galesville Sandstone - The Galesville Sandstone, below the Ironton, is a fine-grained, well sorted sandstone that varies from a few to 100 feet in thickness. The Galesville is friable, porous, and permeable. It is an excellent aquifer.

Eau Claire Formation - The Eau Claire Formation underlies the Galesville and consists of alternating thin beds of fine-grained sandstone, siltstone, shale, and dolomite. In northeastern Illinois the upper member of the formation is commonly a pink to grayish orange siltstone with a high feldspar content. It is very dolomitic in the upper few feet and contains thin interbeds of red and green shale. The middle member consists of glauconitic dolomite or limestone. It contains numerous beds of green shale that become increasingly prominent southeastward in the area. The lower member of the Eau Claire is a fine-grained sandstone that is interbedded with thin layers of red or green shale. The Eau Claire is 370 to 450 feet thick.

Mt. Simon Sandstone - The Mt. Simon Sandstone consists of white to pink, fine- to coarse-grained sandstone that unconformably overlies the Precambrian basement. This sandstone is coarser grained, more poorly sorted, and more angular than any of the other Cambrian or Ordovician sandstones. It is generally friable and porous, but it contains lenses of sandstone that are well cemented with quartz. Red and green micaceous shales are present in beds less than an inch to a few feet thick, especially from 300 to 500 feet below the top of the formation. An arkosic zone with abundant pink feldspar is commonly present at the base of the Mt. Simon. The Mt. Simon is estimated to be 1700 to 2400 feet thick in the area.

Precambrian Rocks

Although no wells have been drilled to the Precambrian in this area, data from wells just outside the area permit inferences concerning the surface of the basement rocks. The top of the Precambrian is estimated to be from 3000 to over 4000 feet below the surface in the Chicago area. Near-by wells that have penetrated the Precambrian encountered red granite that is about 1.3 billion years old. The topographic surface of the Precambrian at the beginning of Mt. Simon deposition probably had local relief of several hundred feet.

GEOLOGIC INVESTIGATIONS

Geologic investigations for the Chicagoland Deep Tunnel Project were conducted by Harza Engineering Company in two stages. Stage I included the investigation, collection, analysis, and evaluation of existing data. Quarries and natural outcrops in the area were visited, as were mines in the Ordovician rocks of northwestern Illinois and southwestern Wisconsin. A thorough search of publications and subsurface data was made and more than 3000 logs of boreholes that had reached bedrock in the area were plotted.

Stage II involved exploration of the subsurface to confirm and refine the interpretations made in stage I and to obtain rock samples for laboratory analyses. The exploration program included test drilling, geophysical logging of boreholes, laboratory testing of rock samples, seismic surveying, and groundwater testing.

Test Drilling

Twenty-four holes were drilled by Dikor-Groves to obtain rock cores. The cores provided rock samples for laboratory analyses, positive stratigraphic control, and correlation between the rock layers, the geophysical borehole logs, and the logs from previously drilled holes. The water-bearing properties of the rocks were evaluated and monitored in the boreholes. A total of 11 soil exploration holes also was drilled to sample the glacial drift in the vicinity of a proposed surface reservoir near Lake Calumet. The total footage drilled for this exploration program was 34,360 feet. The deepest hole, 1696 feet deep, reached the top of the Eau Claire Formation. Most of the bedrock holes were cored into the St. Peter Sandstone and had total depths of about 1000 feet. Core recovery was excellent through all formations.

Geophysical Logging of Boreholes

Geophysical logging of boreholes produces a record of the in-situ response of the rock strata to various measuring devices lowered into the borehole. Logging devices must be calibrated to provide uniform results from one borehole to another. Variations in borehole conditions caused by changes in diameter, the presence or absence of fluid, or the presence or absence of casing will affect the response of the rock strata to some of the measuring devices. The logging program conducted by Birdwell Division included gamma-ray, neutron, formation density, 3-D velocity, temperature, and caliper logs (fig. 4).

Gamma-Ray Log

The gamma-ray log records the natural radioactivity of rocks in holes that are either fluid-filled or dry and either cased or uncased. Shales normally contain higher percentages of the radioactive elements uranium, thorium, and potassium than do other sedimentary rocks. Low gamma-ray intensities are recorded graphically as a deflection to the left, and high gamma-ray intensities are recorded as a deflection to the right.

Neutron Log

The neutron log records the hydrogen content of rocks in either fluid-filled or dry holes, cased or uncased. The logging tool emits neutrons at high velocity that collide elastically with atoms within the surrounding rock formations. Because of the similarity of masses, the collision of neutrons with hydrogen atoms causes the neutrons to lose velocity and eventually be captured. Capture is accompanied by the emission of gamma rays of capture, which are measured by a detector set at a fixed distance from the source of neutrons. As hydrogen content is closely related to porosity because hydrogen is abundant in the fluid-filled pore spaces, the neutron log is a porosity indicator. A deflection of the graphic record to the left indicates a high hydrogen content (higher porosity) and a deflection to the right indicates a low hydrogen content (lower porosity).

Formation Density Log

The formation density log records the bulk density of rocks in uncased holes that are fluid-filled or dry. The logging tool emits gamma rays that are reflected by electrons in the rock back to a measuring device in the logging tool. The intensity of the reflected rays depends upon the electron density of the rock, which is directly proportional to the bulk density of the rock strata. A deflection of the graphic record to the left indicates low density, and a deflection to the right indicates high density.

3-D Velocity Log

The 3-D velocity log is a sonic log that records time and provides velocities of the shear wave and the pressure wave in fluid-filled and, preferably, uncased holes. The velocity data and the density data are utilized to compute the Poisson's ratio and the Young's (elastic) modulus of the rock. The

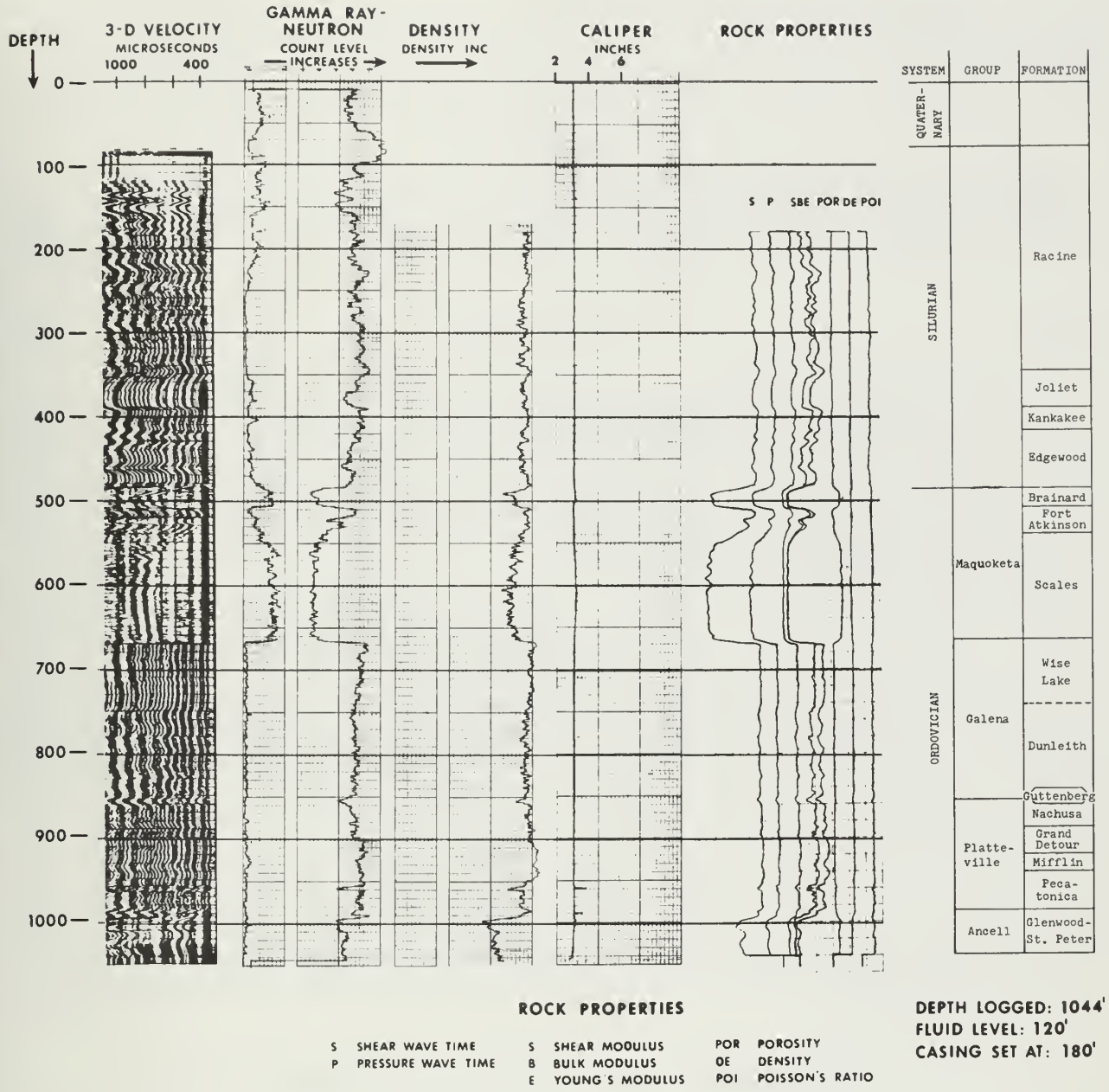


Fig. 4 - Geophysical data from boreholes (by Birdwell Division).

mathematical relations used to calculate the moduli values and Poisson's ratio from the geophysical logs are as follows:

Shear modulus

$$\mu = DV_s^2$$

Bulk modulus

$$B = DV_p^2 - 4\,\mu/3 \text{ or } B = D\left(V_p^2 - \frac{4}{3}V_s^2\right)$$

Poisson's ratio

$$\sigma = \frac{(V_p/V_s)^2 - 2}{2(V_p/V_s)^2 - 2}$$

Young's modulus

$$E = 2 \mu (1 + \sigma)$$

where

μ = shear modulus
D = formation bulk density
V_s = velocity of the shear wave
B = bulk modulus
V_p = velocity of the pressure wave
σ = Poisson's ratio
E = Young's modulus

Temperature Log

The temperature log records the temperature in the borehole in a fluid-filled or dry hole. Temperatures measured in boreholes in the Chicago area generally ranged from 45° F to 60° F, with the temperatures normally increasing with depth. The rate of increase (geothermal gradient) is from 0.5° F to 1.0° F per hundred feet of depth.

Caliper Log

The caliper log records the borehole diameter. The measurements are used to interpret fluctuations recorded by other logs and to determine the condition of the borehole.

Geophysical Characteristics of the Rocks

Some engineering properties of the rocks, such as porosity, density, travel time of shear and pressure waves, shear modulus, bulk modulus, and Young's modulus, can be interpreted from the geophysical logs of boreholes. The rock properties and their geophysical characteristics are commonly different in each stratigraphic unit. These differences are summarized in table 1. The characteristics for a stratigraphic unit are not indicated as absolute measurements, but instead they are indicated as relative measurements compared to the immediately overlying stratigraphic unit.

Laboratory Testing of Samples

Selected rock and soil samples were analyzed by Harza Engineering Company in their laboratory to determine the range of properties of the various

strata. In general, the rocks were analyzed for their specific gravity, unconfined compressive strength, modulus of elasticity, drillability, natural water content, absorption, abrasion, porosity, permeability, solubility, and reaction to wetting and drying. Petrographic and X-ray determinations were made of the mineralogy of the rocks.

The samples of soils and glacial drift were analyzed to determine their grain-size distribution, water content, Atterberg limits, unit weight, unconfined compressive strength, triaxial compression, consolidation, and permeability.

Seismic Survey

A seismic exploration program was conducted by Seismograph Service Corporation in the Chicago area to map both the bedrock topography and the geologic structure of the top of the Galena Group. The seismic survey was laid out on a basic 4-mile grid spacing in what was referred to as the Master Plan Area and on a basic 2-mile east-west spacing and 4-mile north-south spacing in the Lake Calumet area. Minor modifications in the basic layout were made to accommodate variations in the city street system and to obtain more detailed subsurface information in certain areas. Approximately 420 miles of seismic traverses were made during 1967 and 1968 (fig. 5). No seismic program approaching this magnitude had ever before been conducted in the Chicago area. The 33,600 datum points derived from the program provide important subsurface information, especially in areas that lack drilling data. However, contouring of the seismic points and borehole data is necessarily interpretative, and it must be further refined as new data become available.

The Vibroseis (Continental Oil Company) system of seismic exploration was selected by the Metropolitan Sanitary District for this investigation because, of the several seismic systems considered, it was the most adaptable to an urban environment (Mossman et al., 1971). Seismic operations in a municipal area require that there be a minimum interruption of traffic, relatively little noise produced, no damage to streets or underground structures, and an ability to filter out or distinguish the seismic signal from the high ambient noise level.

The Vibroseis system utilizes a low-power signal that is readily distinguishable from the background noise. The signal is produced by a vibrating source placed directly on the surface of the pavement (fig. 6), and its duration and frequency can be varied to obtain optimum results.

The bedrock surface was mapped by refraction techniques, and the top of the Galena was mapped by reflection techniques. Continuous profiles were obtained along each line of traverse.

Preliminary processing of the seismic data was performed in a field office, and final data processing was completed in the home office of the Seismograph Service Corporation. To convert the travel time measurements to depth values, the velocities of the various strata were determined. Velocity was obtained both by direct measurements in boreholes and by correlation of the seismic data with depth to formation tops reported in the boreholes.

TABLE 1—PHYSICAL PROPERTIES OF STRATIGRAPHIC UNITS DETERMINED FROM GEOPHYSICAL LOGS
(Values indicated for each unit are relative to those of immediately overlying unit.* Data from Birdwell Division.)

Stratigraphic unit	Shear wave		Pressure wave		Shear modulus		Bulk modulus		Young's modulus				
	Velocity	Uniformity	Velocity	Uniformity	psi	Uniformity	psi	Uniformity	psi	Uniformity	Gamma ray	Neutron	Resistivity
Racine Formation (undifferentiated; used as standard)													
Reef	I	SV	I	SV	I	SV	I	SV	I	SV	←	→	
Interreef	D	V	D	V	D	V	D	V	D	V	→	←	
Joliet Formation													
Romeo Member	I	U	I	U	I	U	I	U	I	U	ND	→	
Markgraf Member	D	U	D	U	D	U	D	U	D	U	→	←	
Kankakee Formation	I	SV	I	SV	I	U	I	SV	I	SV	←	→	
Edgewood Formation	D	SV	D	SV	D	SV	D	V	D	V	←	→	
Brainard Formation	D	U	D	U	D	U	D	U	D	U	→	←	
Fort Atkinson Formation	I	V	I	V	I	SV	I	V	I	V	←	→	
Scales Formation	D	U	D	U	D	U	D	U	D	U	→	←	
Wise Lake Formation	I	U	I	U	I	U	I	U	I	U	←	→	
Dunleith Formation	SD	SV	SD	SV	SD	U	SD	SV	SD	SV	ND	ND	
Guttenberg Formation	D	U	D	U	D	U	D	U	D	U	ND	←	
Nachusa Formation	I	U	I	U	I	U	I	U	I	U	ND	→	
Grand Detour Formation	SI	U	SI	U	SI	U	SI	U	SI	U	ND	→	
Mifflin Formation	D	U	D	U	D	U	D	U	D	U	→	←	
Pecatonica Formation	I	U	I	U	I	U	I	U	I	U	←	→	→
Glenwood—St. Peter Formation	D	U	D	U	D	U	D	U	D	U	ND	←	←
Potosi Formation	SI	SV	SI	SV	SI	SV	I	V	I	V			→
Franconia Formation	D	V	D	V	SD	SV	D	V	D	V	→	←	←
Ironton Formation	SD	V	SI	V	SD	SV	SI	SV	ND	SV	←	→	→
Galesville Formation	D	V	SD	SV	SD	U	SD	U	SD	U	ND	ND	←
Eau Claire Formation	I	I	I		I		I		I		→	→	←

* I - increase S - Slight U - Uniform → - Deflection to right
D - decrease V - Variation ND - Not distinctive ← - Deflection to left

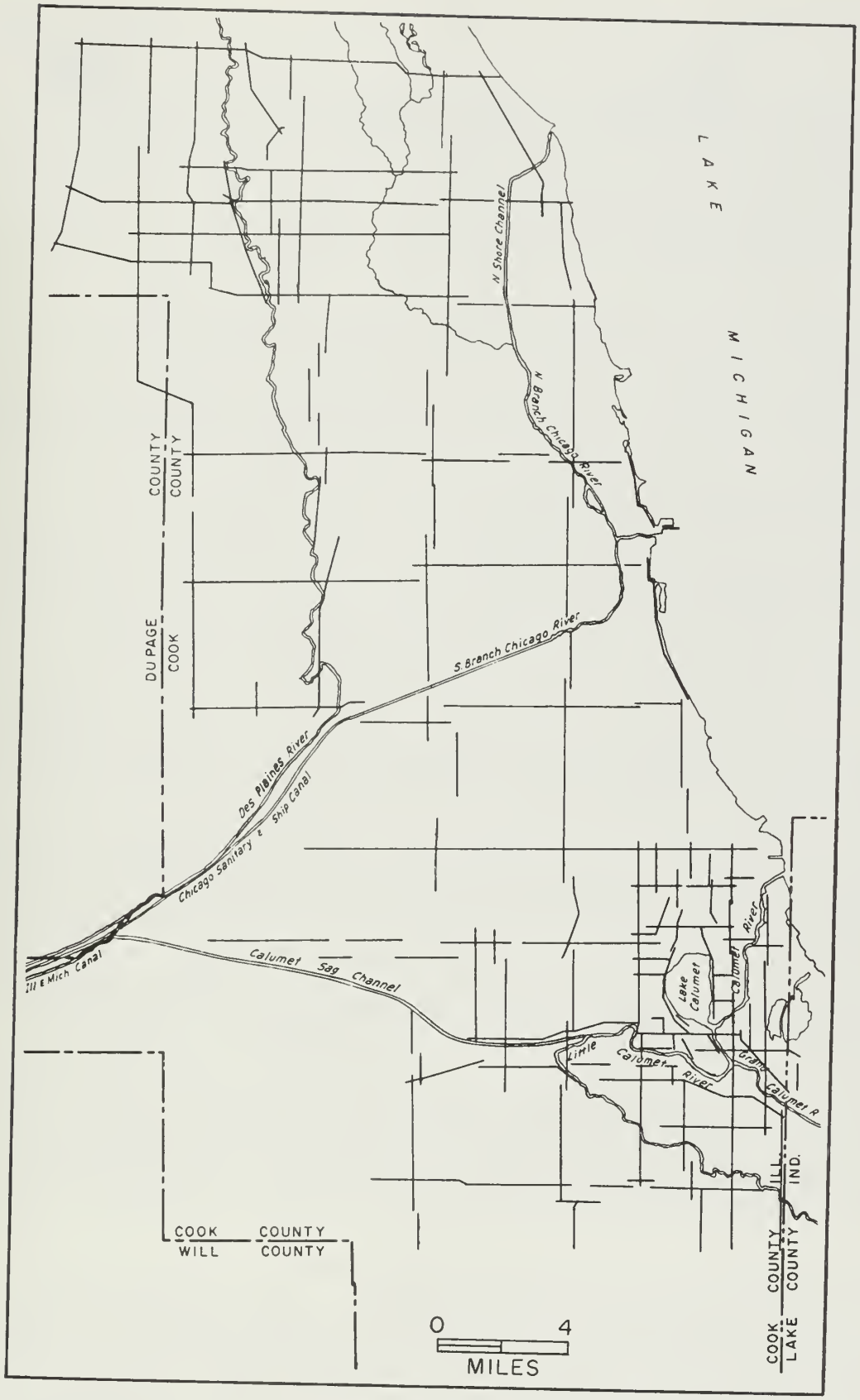


Fig. 5 - Location of seismic traverses (from drawing by Seismograph Service Corporation).

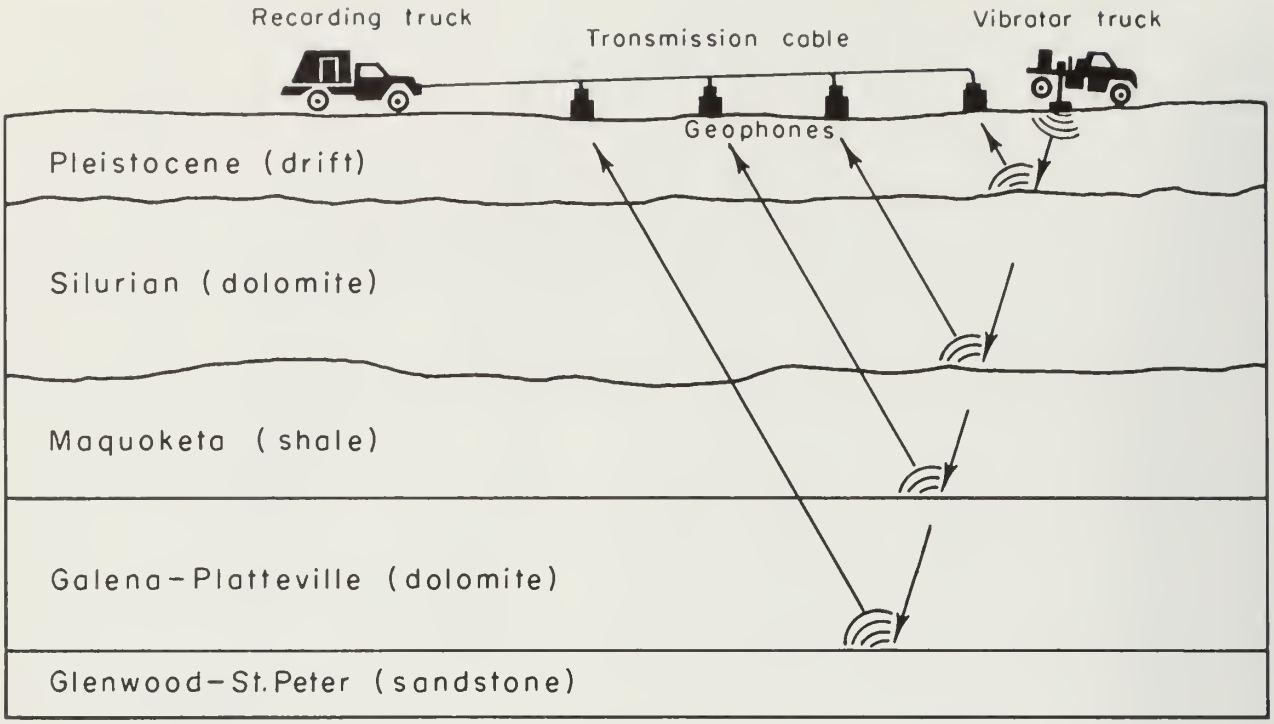


Fig. 6 - Diagrammatic cross section showing Vibroseis operation.

Good correlation was obtained between the seismic data and the depth to formation tops reported in most drill hole logs. Fault displacements reported along the seismic traverses are expected to be accurate within plus or minus 15 feet.

The results of the seismic survey were presented in contour maps and cross sections. The maps (figs. 7 and 8) are based on all available borehole data from the files of the Illinois State Geological Survey and on the calculated seismic depths. They present new interpretations of the configuration of the bedrock surface and the surface at the top of the Galena Group. To include borehole information obtained since the seismic survey, the maps have been modified slightly for this report and have been expanded along the west side to tie them in with existing regional maps.

A structural anomaly, the Des Plaines Disturbance, occurs in the northern part of the area. The disturbance is an area of about 25 square miles that includes many high-angle faults. The bedrock consists of dolomites, sandstones, and shales of various ages. Because this locality is anomalous to the regional structure and bedrock surface, it is treated separately in this report.

Bedrock Surface

The bedrock in the Chicago area is chiefly Silurian dolomite. It is overlain by glacial drift and, locally, by artificial fill. The thickness of the overburden ranges from zero, where the rock crops out, to about 200 feet. The configuration of the bedrock surface is the result of structural deformation, weathering, and erosion. The period of weathering and erosion to which

the bedrock was subjected was sufficiently long to obliterate any structural trends that may have been present.

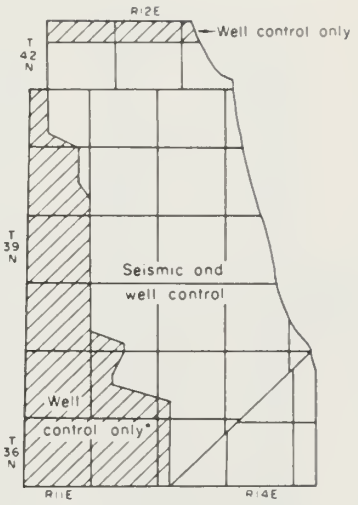
Previous interpretations of the bedrock topography were based on outcrop data and borehole records (Horberg, 1950; Suter et al., 1959; Hughes et al., 1966) and depicted a gently rolling, dissected bedrock surface with an integrated drainage system. Divides were generally shown to be 3 to 4 miles wide. The valleys had a general east-west trend and sloped to the east. The more prominent valleys were shown to be 50 to 100 feet deep and about a mile wide at the top. No closed depressions were mapped by either Horberg or Hughes et al.

A new interpretation of the configuration of the bedrock surface, based on the 33,600 plotted points derived from seismic refraction data, information from more than 3000 boreholes, and outcrop data was prepared by Seismograph Service Corporation (fig. 7). The range of accuracy of the data to the top of bedrock obtained by seismic methods is believed to be plus or minus 10 feet. Excellent correlation was found to exist in most instances between the seismically derived data and the borehole data. In the few instances where the seismic data and the borehole data failed to correlate, the lack of correlation was probably the result of (1) variations in the seismic velocity of the overburden material, (2) the presence of a zone of weathered rock that could not be identified by seismic methods, or (3) an error in the reported location or elevation of the boring. Weathered rock is suspected in sections 1, 2, and 3, T. 38 N., R. 11 E., and in sections 7, 8, 17, and 18, T. 39 N., R. 11 E. In those areas, the seismic data indicate the top of "sound," unweathered rock.

The configuration of the bedrock topography as depicted on figure 7 can be described as a dissected surface with numerous hills, northeast-southwest to east-west trending valleys that slope to the east, and enclosed depressions. The regional slope of the bedrock surface is east and northeast. The elevation of the bedrock surface is generally between 500 to 600 feet above sea level, but it ranges from a high of more than 650 feet in the western part of the area to a low of less than 470 feet above sea level in the eastern part.

The interpretation of the bedrock topography differs from the previous interpretations in indicating that closed depressions are present throughout the area. The depressions are approximately 10 feet deep, with an interpreted maximum depth of 30 to 40 feet. They cover an area of from less than a quarter of a square mile to more than 4 square miles. The presence of the depressions suggests that a karst topography had developed. Otto (1963) showed many depressions in the bedrock surface in an area north of Joliet and suggested the possibility of closed depressions on the bedrock surface of the Chicago area.

Faulting in the area is believed to have occurred following the deposition of the Silurian strata. Faults in the Silurian have been reported in natural outcrops and quarries in the Chicago area. Displacements along the known faults total a few inches to a few feet, but most are less than 1 foot. The inability of the seismic program to detect faulting in the Silurian strata indicates the absence of wide shear zones or fault scarps more than 10 feet high on the bedrock surface.



*(After Suter et al, 1959)

Contour, intervol 20 feet (50 feet in oreo of well control only); dotum sea level

Closed depression

0 2 4 mi
0 2 4 km

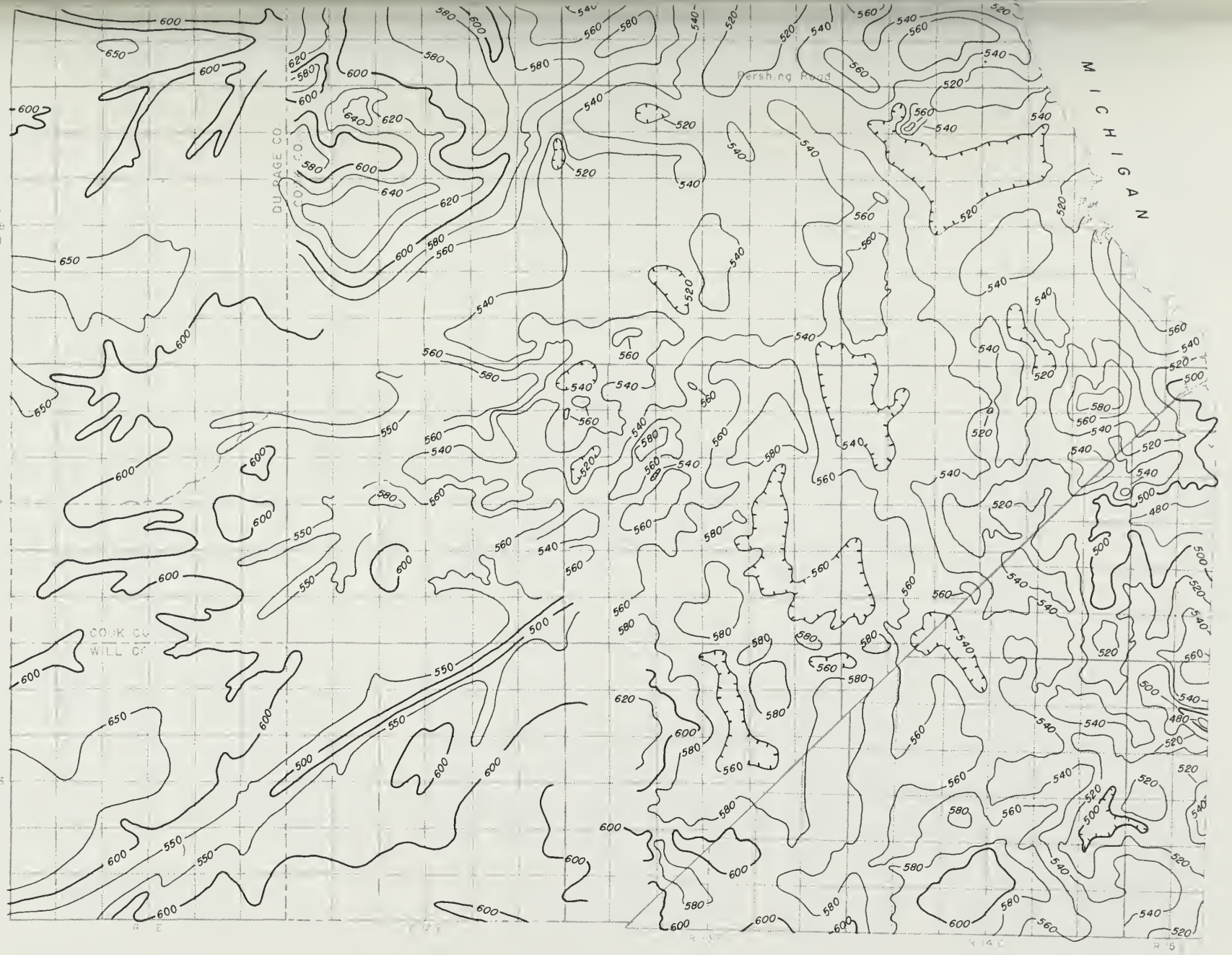


Fig. 7 - Topography of bedrock surface (modified from maps prepared by Seismograph Service Corporation). The Des Plaines Disturbance boundaries here separate Silurian from non-Silurian bedrock.

Structure on Top of Galena Group

The rocks assigned to the Galena Group and to the underlying Platteville Group are primarily dolomite. The Galena is overlain by shales of the Maquoketa Group and the Platteville is underlain by sandstones of the Ancell Group. The combined thickness of the Galena and Platteville Groups typically ranges from 300 to 330 feet.

A structure map of the top of the Galena (fig. 8) has been modified slightly from one prepared by Seismograph Service Corporation to include borehole data obtained since 1968. The original configuration was based on the plotted points derived from seismic reflection data and information from more than 300 boreholes that reached the Galena.

Excellent correlation was found in most instances between seismically derived data and the borehole data. Where there is a lack of correlation, local variations that affect the seismic signals or errors in the reported location or elevation of the borings probably are responsible. The range of accuracy of data to the top of the Galena obtained by seismic methods is believed to be plus or minus 25 feet.

The configuration of the surface of the Galena is the result of structural deformation and minor erosion. The regional structural trends have a north-south strike with a gentle dip to the east, modified by a series of east to west undulations. The elevation of the top of the Galena ranges from a little over 300 feet above sea level in the northwestern part of the area to about 150 feet below sea level in the southeastern part. Throughout most of the area the dip is 10 to 15 feet per mile in an easterly direction. The east to west undulations are a series of anticlinal noses that plunge eastward. Many of the noses have structural domes along their crests that have 25 to 50 feet of closure. Locally the adjacent synclines contain structural basins with 25 to 50 feet of closure.

The seismic survey suggests the presence of numerous faults (fig. 8), which are tabulated in table 2.

Des Plaines Disturbance

The Des Plaines Disturbance is a local structural anomaly centered at Des Plaines, T. 41 N., R. 12 E., Cook County. This area of about 25 square miles contains numerous high-angle faults. Displacements of as much as 600 feet have brought rocks as old as the Prairie du Chien Group (basal Ordovician) to the bedrock surface and carried downward and preserved Mississippian and Pennsylvanian strata that in the surrounding area have subsequently been completely eroded.

A study of the structure by Emrich and Bergstrom (1962) was based on records of 295 wells, for only 102 of which were samples preserved. No other information was available. With the seismic data now available, more precise interpretations are possible, particularly of the bedrock surface, the extent of the disturbance, and the locations of faults.

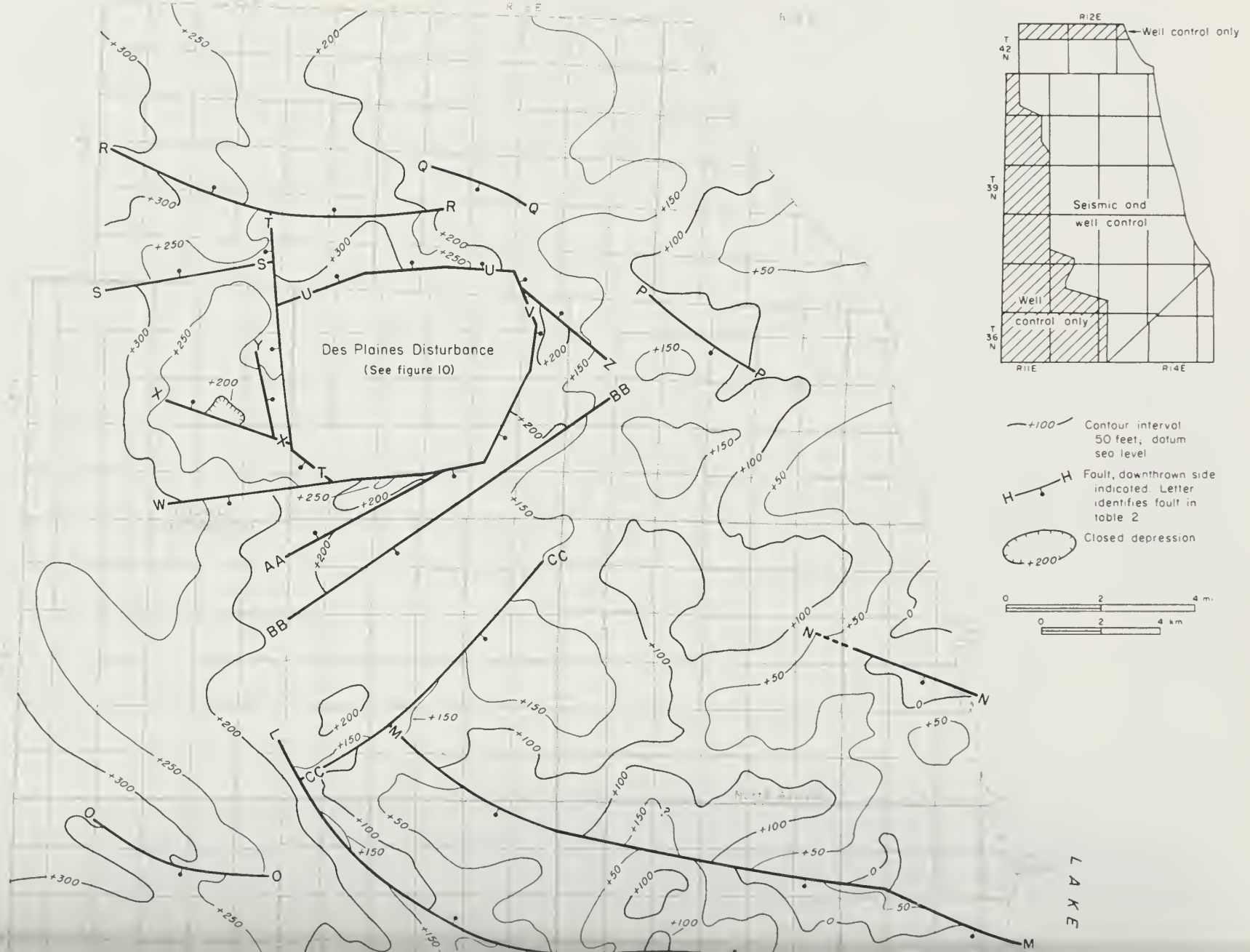
The bedrock surface within the area of the disturbance (fig. 9) appears to be slightly lower than the bedrock surface of the surrounding area.

TABLE 2—DISPLACEMENTS OF INFERRED FAULTS ON STRUCTURE MAP OF TOP OF GALENA GROUP

Fault	Displacement (ft)	Downthrown
A-A	Slight	North
B-B	30-55	South
C-C	20-30	North and east
D-D	Slight	North
E-E	< 20	North
F-F	≈15	North
G-G	15-25	North
H-H	10-25	South
I-I	25	North
J-J	15 - < 50	South
K-K	10-15	Southwest
L-L	≈50	Northeast
M-M	25	South
N-N	40	South
O-O	≈ 25	South
P-P	≈ 55	Southwest
Q-Q	?	?
R-R	30-50	North
S-S	≈25	North
T-T	Des Plaines Complex	West
U-U	Des Plaines Complex	North
V-V	Des Plaines Complex	East
W-W	Des Plaines Complex	South
X-X	Des Plaines Complex	North
Y-Y	Des Plaines Complex	East
Z-Z	Des Plaines Complex	Northeast
AA-AA	25	North
BB-BB	≈ 50	Southeast
CC-CC	50	Southeast
DD-DD	?	South
EE-EE	≈30-50	Southwest
FF-FF	≈30-50	Southwest

Patterns of highs and lows outside the structure do not correlate with those within the disturbed area, particularly where the bedrock is not Silurian dolomite. Differential erosion of the various rock types that cap the fault blocks possibly accounts for the anomalous configuration of the bedrock surface.

The general outline of the disturbance is not much changed from previous interpretations, but the interpreted faults extending outward from and surrounding the structure form a more complex arrangement of fault blocks than was previously depicted. Structure contours were drawn by Seismograph Service Corporation for the fault blocks (figs. 8 and 10) where a seismic contrast


Des Plaines Disturbance
(See figure 10)
R12E
T 42 N
T 39 N
T 36 N
R11E
R14E
Well control only
Seismic and well control
Well control only
Contour interval 50 feet, datum sea level
Fault, downthrown side indicated. Letter identifies fault in table 2
Closed depression
0 2 4 mi
0 2 4 km
LAKE

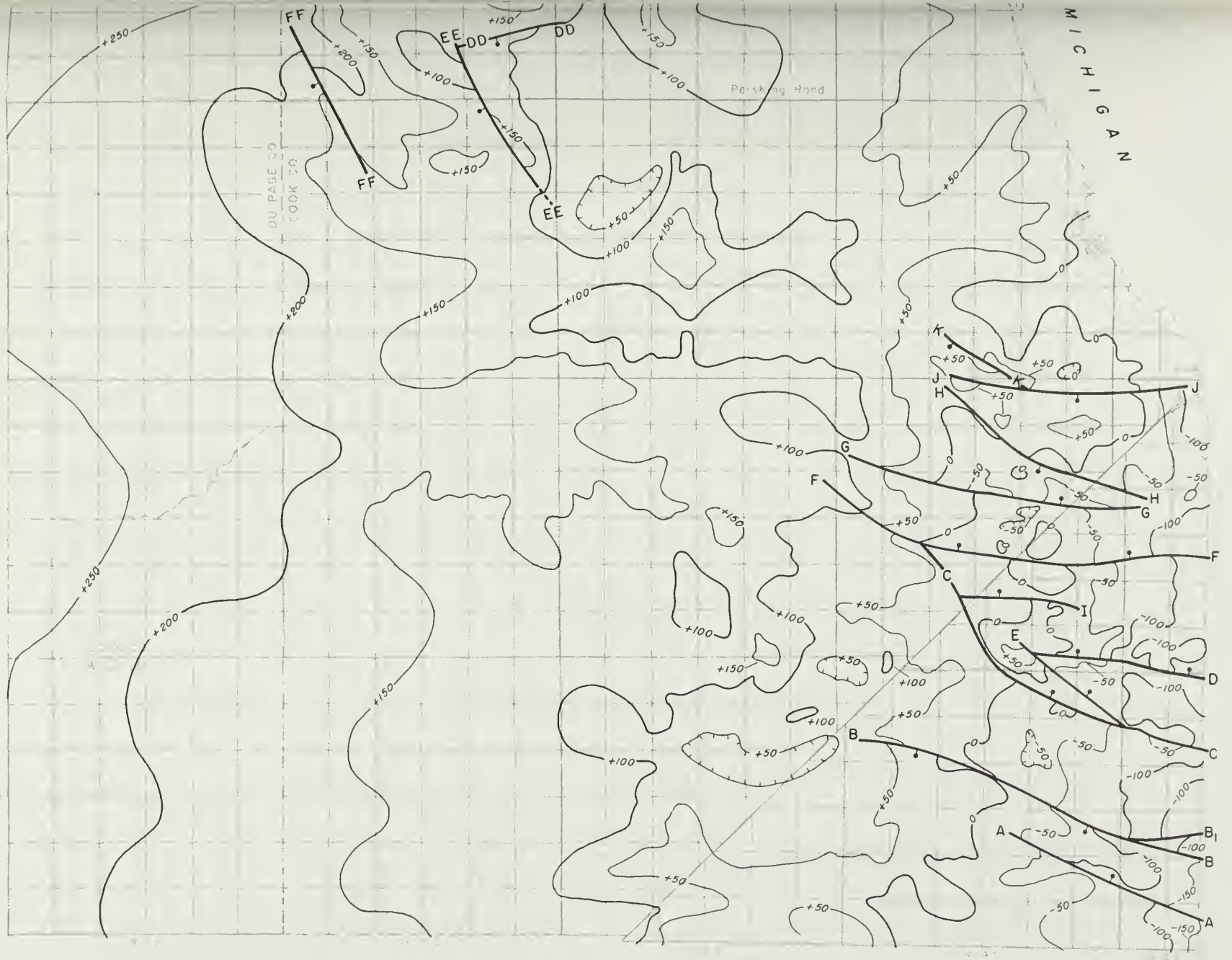


Fig. 8 - Structure on top of Galena Group (modified from maps prepared by Seismograph Service Corporation). The Des Plaines Disturbance here is bounded by fault lines.

Fig. 9 - Topography of bedrock surface in the Des Plaines Disturbance (map prepared by Seismograph Service Corporation).

could be interpreted. However, the age of the rocks composing the bedrock surface and the deeper rocks was not ascertainable from the seismic data and could be inferred only from existing geologic information.

Ground-Water Testing

A ground-water testing program was carried out by Layne-Western Company to evaluate the technical and economic feasibility of the system proposed for protecting the aquifers and to estimate the amount of ground water that would seep into the conveyance tunnels and storage reservoirs (see Heim, Mossman, and Lawrence, 1971). The ground-water studies included a review of the existing data, analog model studies, an extensive field testing program, and laboratory analyses of the ground water. Aquifers in the Silurian, Ordovician, and Cambrian strata were evaluated by Layne-Western Company. Seepage into tunnels proved to be difficult to estimate because it was impossible to predict the presence of local porous zones or joints in the rocks (see Papadopulos, Larsen, and Neil, 1969).

Concept of the Aquifer Protection System

The Deep Tunnel Project proposes a series of lined or unlined conveyance tunnels located in the Silurian strata, unlined tunnels in the Galena-Platteville strata, and one or more unlined storage reservoirs in the Galena-Platteville strata. Lined shafts through the Maquoketa Shale Group have been proposed to connect the tunnels in the Silurian with those in the Galena-Platteville.

The concept of the method of aquifer protection is relatively simple. It consists of maintaining a higher hydraulic head outside the tunnels and storage reservoirs than is present inside. When future pumpage of ground water lowers the hydraulic head in the tunnel area, artificial recharge can be applied. This will insure that any seepage will be inward rather than outward, thereby protecting the adjacent aquifers.

The conveyance tunnels located in the Silurian strata will be below the present piezometric surface (fig. 11) and the maximum internal head in these tunnels will be less than the external head. Natural recharge appears to be sufficient to maintain the ground-water levels in the Silurian because of the modest amount of pumpage from that aquifer. Therefore, outward seepage should not occur.

The piezometric level in the Cambrian and Ordovician aquifer system in the Chicagoland area has been declining at an average rate of 13 feet per year. The position of the piezometric level in the Galena-Platteville in 1968 was above the proposed Galena-Platteville tunnels and the storage reservoir (fig. 11), but the future position of the piezometric level in the same strata will be below the proposed Galena-Platteville tunnels and the storage reservoir. However, the piezometric level in the aquifer can be maintained above the internal pressure head by means of a system of recharge wells that will artificially maintain a mound of ground water over the tunnels and storage reservoirs.

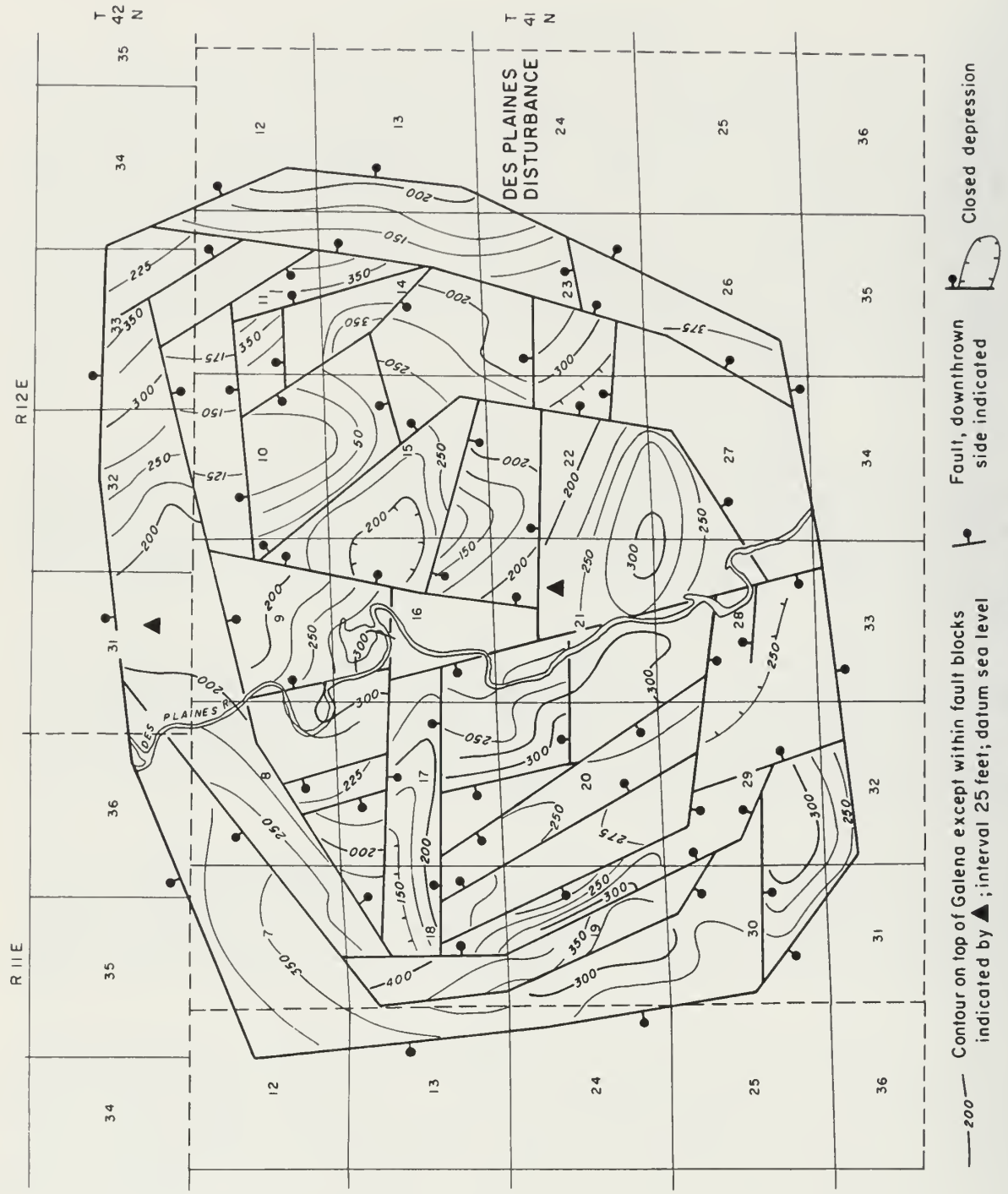


Fig. 10 - Structure in the Des Plaines Disturbance (map prepared by Seismograph Service Corporation).

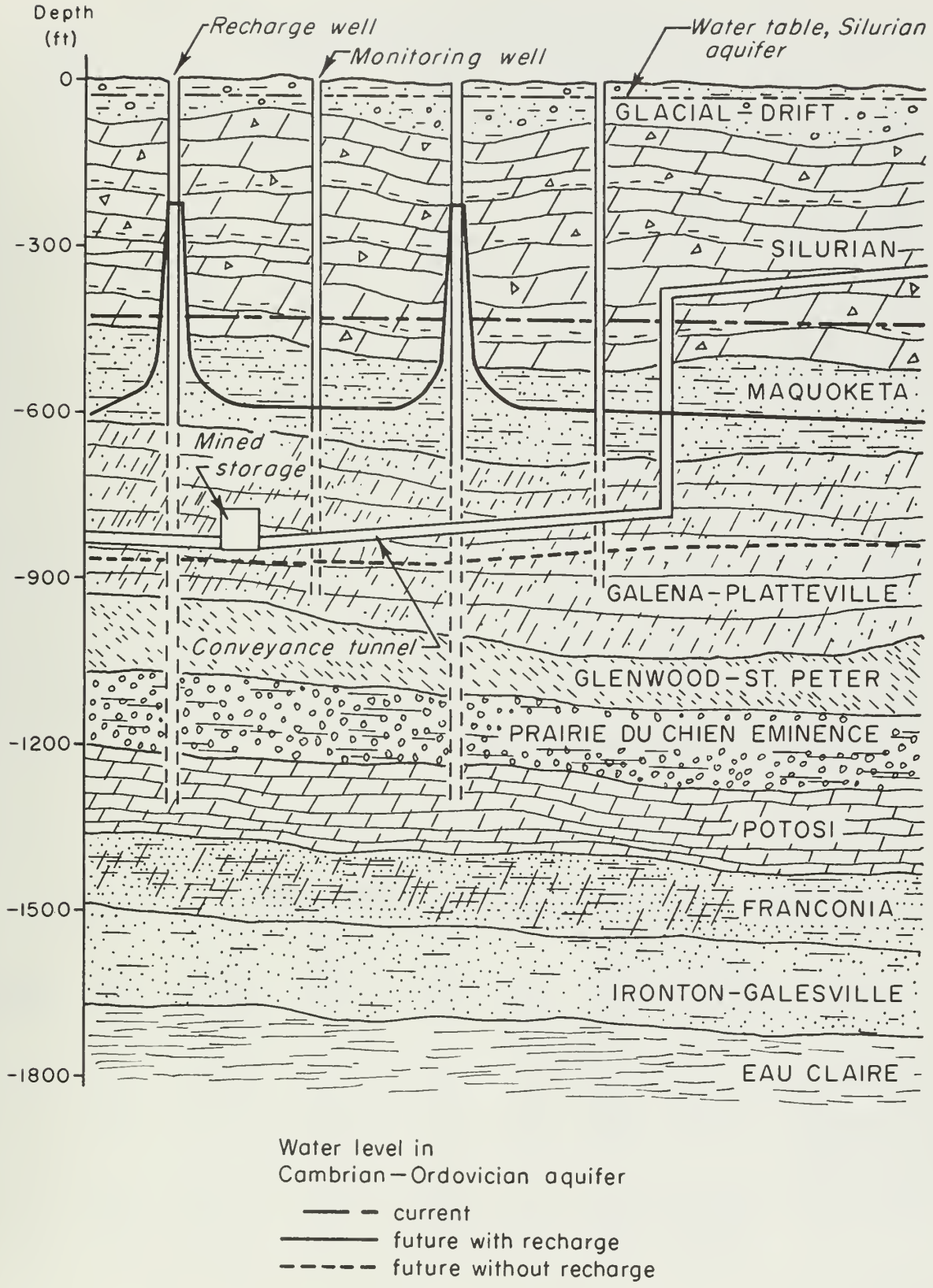


Fig. 11 - Present and projected piezometric levels in relation to proposed aquifer protection system (from drawing by Harza Engineering Company).

TABLE 3—PUMPING TEST INFORMATION OF SPECIFIC CAPACITY WELLS

Well	Depth (ft)	Date tested	Length of test (min)	Nonpumping level (ft)	Pumping rate (gpm)	Drawdown (ft)	Specific capacity (gpm/ft)
			Silurian Tests				
SW-1	453	12-67	49	35	10	121	0.083
SW-2	550	12-67	224	46	30	332	0.090
SW-3	426	1-68	677	16	56	385	0.145
SW-4	549	1-68 1-68	629* 699†	42	60	347	0.173
SW-5	489	1-68	720	28	60	64	0.940
SW-6	533	2-68	721	46	30	357	0.084
			Ordovician Galena-Platteville Tests				
SW-1	874	12-68	720	453	40	145	0.276
SW-2	989	1-68	719	357	30	292	0.103
SW-3	913	1-68	721	433	50	267	0.187
SW-4	970	3-68	56	395	30	411	0.073
SW-5	880	1-68	720	503	60	53	1.120
SW-6	970	2-68	45	431	40	398	0.100

* Length of test before treatment with acid.
† Length of test after treatment with acid.

TABLE 4—PUMPING TEST IN DEEP AQUIFER TEST SITE

Aquifers tested	Depth (ft)		Date tested	Length of test (min)	Nonpumping level (ft)	Pumping rate (gpm)	Drawdown (ft)	Specific capacity (gpm/ft)
	Top of bottom packer	Bottom of top packer						
Silurian aquifer	495.0*	60.0†	12-67	158	24	40	407.0	0.098
Cambrian-Ordovician aquifer	1684.0*	614.0†	2-68	1844	434	380	26.4	14.400
Galena-Platteville	900.0	614.0†	2-68	31	439	40	401.0	0.100
Glenwood—St. Peter	1016.9	919.6	2-68	1773	435	41	310.1	0.132
Prairie Du Chien, Eminence, and Potosi	1366.7	1116.1	2-68	1825	434	350	26.9	13.020
Franconia	1478.6	1378.7	2-68	1841	434	300	237.0	1.266
Ironton-Galesville	1684.0*	1499.6	1-68	1808	434	300	100.0	3.000

* Bottom of well.
† Bottom of casing.

TABLE 5—CHEMICAL ANALYSES OF GROUND WATERS
(Water analyses made by the Illinois State Water Survey)

Well	Aquifer	Fe (ppm)	SiO_2 (ppm)	F (ppm)	Cl (ppm)	NO_3 (ppm)	SO_4 (ppm)	Alkalinity as $CaCO_3$ (ppm)	Hardness as $CaCO_3$ (ppm)	Total dissolved minerals (ppm)	Turbidity (ppm)	Odor	Remarks
SW-1	Silurian	78	12.1	1.4	31	0.6	16.0	296	134	408	1880	0	Sample collected 49 min after pumping at a rate of 10 gpm
SW-2	Silurian	296	—	2.6	46	0.5	8.0	306	136	432	7980	0	Sample collected 2½ hr after pumping at a rate of 30 gpm
SW-3	Silurian	0.7	—	1.6	4	0.3	43.6	222	62	318	2	0	Sample collected 23½ hr after pumping at a rate of 55 gpm
SW-4	Silurian	0.7	—	1.4	8	1.8	172.6	206	68	480	6	0	Sample collected 11 hr after pumping at a rate of 30 gpm
SW-5	Silurian	0.1	—	0.4	13	0.3	11.9	132	114	180	1	H_2S	Sample collected 18 hr after pumping at a rate of 60 gpm
SW-6	Silurian	0.8	—	1.6	22	0.3	0.6	172	14	240	2	0	Sample collected 12 hr after pumping at a rate of 30 gpm
TW-1	Silurian	64	—	1.4	33	1.7	28.2	340	144	443	3080	0	Sample collected 2½ hr after pumping at a rate of 40 gpm
SW-1	Galena-Plateville	0.7	—	3.5	210	1.8	158.8	336	110	952	2	H_2S	Sample collected 12 hr after pumping at a rate of 40 gpm
SW-2	Galena-Plateville	6.4	—	1.4	385	0.2	661.5	208	576	1872	19	0	Sample collected 12 hr after pumping at a rate of 30 gpm
SW-3	Galena-Plateville	0.5	—	1.4	200	0.2	680.9	232	690	1561	2	0	Sample collected 13½ hr after pumping at a rate of 50 gpm
SW-4	Galena-Plateville	8.4	—	1.2	380	0.9	643.6	216	548	1732	50	0	Sample collected 56 min after pumping at a rate of 30 gpm
SW-5	Galena-Plateville	0.5	—	1.8	185	1.8	363.1	268	266	1111	3	0	Sample collected 11½ hr after pumping at a rate of 60 gpm
SW-6	Galena-Plateville	6.2	—	1.8	420	0.8	885.7	214	795	2206	36	0	Sample collected 45 min after pumping at a rate of 40 gpm
TW-1	Galena-Plateville	17	—	1.4	265	0.3	652.3	212	620	1567	50	0	Sample collected ½ hr after pumping at a rate of 40 gpm
TW-1	St. Peter	0.5	—	1.2	275	0.2	736.2	218	745	1727	2	0	Sample collected 30 hr after pumping at a rate of 40 gpm
TW-1	Prairie du Chien, Eminence, and Potosi	0.4	—	1.4	245	0.6	734.4	212	795	1680	3	0	Sample collected 26 hr after pumping at a rate of 350 gpm
TW-1	Cambrian-Ordovician	0.4	—	1.6	230	1.4	725.7	214	750	1676	2	0	Sample collected 30 hr after pumping at a rate of 380 gpm
TW-1	Franconia	0.3	—	1.6	240	0.2	729.0	208	760	1692	2	0	Sample collected 29 hr after pumping at a rate of 300 gpm
TW-1	Ironton-Galesville	0.9	—	1.0	200	0.2	690.9	222	728	1572	3	0	Sample collected 29 3/4 hr after pumping at a rate of 300 gpm

Field Program and Results

The field testing program consisted of 20 pumping tests and two recharge tests designed to determine the hydrogeologic properties of the aquifers in the Silurian, Ordovician, and Cambrian Systems (Papadopulos, Larsen, and Neil, 1969). The specific capacity of six of the wells in the Silurian and the Galena-Platteville strata was tested, and results of the tests are presented in table 3.

Seven pumping tests were made in the well testing the deep aquifers to determine the hydrogeologic characteristics of the Silurian aquifer, the Cambrian and Ordovician aquifer system, the Galena-Platteville strata, the Glenwood-St. Peter aquifer, the Prairie du Chien, Eminence, and Potosi strata, the Franconia strata, and the Ironton-Galesville aquifer. Although many of the units are interconnected and cannot be entirely isolated physically, each unit tested was isolated as completely as possible by inflatable packers in the test well and in the observation wells during the testing period. The results of the deep aquifer tests are presented in table 4. Chemical analyses of the water from the various water-bearing strata (table 5) were made by the Illinois State Water Survey.

Two recharge tests were conducted to determine how deep the artificial recharge wells must be to maintain the desired piezometric head above the tunnels and storage chambers in the Galena-Platteville strata. During the first test, water was injected into the zone between the top of the Galena and the lower part of the Potosi. In the second test, water was injected into a zone between the top of the Galena and the base of the St. Peter. Analysis of the recharge test data indicated that recharge wells drilled into the Potosi Dolomite would be the more successful in producing an adequate build-up of the piezometric head.

CONCLUSIONS

Geologic investigations for the Deep Tunnel Project furnished a considerable amount of new and detailed information about the rocks in the greater Chicago area. Continued exploration and tunnel excavation will add much more data. The investigations have sharpened rather than altered our stratigraphic interpretation of the rocks in the area.

The seismic study, however, presented a new structural picture, which includes inferred faults with up to 50 feet of displacement and closed depressions on top of the bedrock surface. The proposed tunnels will intersect several of the inferred faults, making it possible to determine whether the actual conditions of the strata correspond to the seismic interpretations.

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